APPENDIX 2
SOILS

The following is a synopsis of Protocol for Evaluating, Designing, Operating and Monitoring Managed Irrigating Systems for Coal Bed Natural Gas Produced water for the Tongue River – Badger Hills Project, Big Horn County, Montana (Kevin Harvey 2003).

At the core of application of produced water is control of the sodium adsorption ratio (SAR) in the soil – water system. Because of naturally low levels of calcium and magnesium and high levels of sodium and bicarbonate result in relatively high SAR values in the produced water, some type of treatment, either of the water and/or soil is required. To lower the SAR and counteract the potential effects of sodium adsorption on soil, either sodium removal or addition calcium or magnesium is necessary.

Coal bed natural gas produced groundwater would be stored in off channel reservoirs during the late fall, winter and early spring months followed by application of the produced water during the irrigation season.

To address the effects to soils and near surface groundwater, several items need to be addressed. These include water balance projections, soil and/or water conditional prescriptions, site selection and characterization, selection and design of irrigation system and development of an irrigation and crop management plan.

Water balance projections would simulate monthly water balances to provide estimates of water production with time, annual storage requirements and annual irrigation area requirements. For this project, a proprietary water balance model was developed by KC Harvey, Inc. Model input includes produced water pumping rates, pumping decline functions, precipitation inflow, reservoir evaporation and percolation rates and irrigation rates. This model includes deterministic functions to reflect project specific operations and probabilistic functions to simulate uncertainty and variability in the water balance associated with climate and pumping rates.

Soil and/or water conditioning prescriptions include laboratory analysis of the water to be used, soils it is applied to and geochemical modeling of water chemistry to derive site specific soils and/or water conditioning prescriptions. Laboratory analysis of water and soil will include: pH, electrical conductively (EC), total dissolved solids (TDS), dissolved cations (calcium, magnesium, sodium, potassium) and dissolved anions (carbonate, bicarbonate, sulfate, chloride). Data would permit an evaluation of the suitability of water for irrigation with respect to salinity and sodicity.

The amounts of soil and/or water amendments to be added are based on the chemistry of the water and the amount of water applied. The geochemical models PHREEQC or MINTEQ would be used to assess the equilibrium chemistry of the applied water with the added amendments. The models are used to determine possible changes in chemistry when produced water is equilibrated with atmospheric pCO_2 levels; to predict if the sulfur and gypsum at various rates of application would dissolve and yield the required amounts of acid and calcium respectively; and to determine if target pH and ESP-SAR goals would be obtained. These soil-water interactions include potential formation of $CaCO_3$ and/or decrease in HCO_3^- levels associated with high soil pCO_2 values.

Model results would be used to calculate soil amendment rates for sulfur and gypsum. These rates would include adjustment for product purity and a safety multiplier to account for imperfect field application, soils it is applied to and soil irrigation variability.

Site selection and characteristics would include screening for candidate sites and soil characterization of final sites to document baseline soils physical and chemical conditions and provide information required to design the land application system.

A number of soil pits would be excavated to characterize major soil types and to facilitate the development of a site soil map. For each soil pit, a soil profile description would be prepared by a qualified soil scientist with USDA protocols. In addition to routine soil profile descriptors, any horizons that may be hydraulically limiting would be identified. Each major soil horizon would be sampled and analyzed for pH, EC, SAR, ESP and other pertinent chemical and physical parameters. In addition, soil infiltration rates would be measured immediately adjacent to each test pit location. Soil permeability testing of the most limiting horizon would be conducted at the appropriate depth.

Irrigation system selection and would be based on topography of the landscape, soil texture, soil infiltration rate, permeability, soil water holding capacity, cropping requirements, climate, landowner preference, size of irrigated area and cost. Possible irrigation equipment options include: center pivot, wheel line, hand move/solid set, big gun, subsurface drip and gated pipe.

Irrigation and crop management addresses procedures for irrigation scheduling, cropping, site monitoring and soil action levels and responses. Irrigation scheduling would be accomplished through the development of a soil-water balance. A site specific soil-water balance is developed using local precipitation, crop evapotranspiration data, sprinkler type efficiencies, soil water holding capacity, crop rooting depth, crop harvesting requirements and leaching requirement. The leaching requirement is calculated to maintain a target average root zone EC based on the salinity thresholds for specific vegetation. Any irrigation rates determined from the soil-water balance must not exceed the infiltration rate of the soil, eliminating potential water run off from the site. Monitoring would be conducted during irrigation season to ensure no runoff occurs.

The cropping plan would detail the specific crops to be grown, seeding rates, seeding methods, site preparation requirements and harvesting methods. Crop selection would be based on landowner preference, salinity tolerance, water use and general site tolerances.

Irrigation site monitoring insures that the applied soil amendments, as calculated, are performed to mitigate any potential impacts caused by sodic water application. Monitoring of the site includes an evaluation of soil chemistry, run off and erosion, water quality and vegetative performance.

Before and after each irrigation season, discrete and/or composite soil samples would be collected from each application area. Discrete samples would generally be collected from 0-6 inch and 6-24 inch depths or based on soil characteristics if appropriate. Composite soil samples would be collected along a random zigzag pattern across the entire site. Soils samples would be analyzed for pH, EC, SAR, exchangeable sodium percentage (ESP), Nitrogen (N), Phosphorus (P) and Potassium (K) and other pertinent parameters.

Both quantity and quality of the irrigation water applied would be monitored. Water samples will be analyzed on a monthly basis for pH, EC, SAR, major cations, major anions and other pertinent parameters. The amount of water applied at each area would be continued measured.

Visual inspections would be made for observable changes in vegetation and soil conditions and to assess and optimize the water management approaches employed. The emergence of new seedlings, height and color of plants and percent ground covered by vegetation, as well as any unusual conditions, such as leaf browning, would be noted.

Site specific soil chemistry action levels would be established for each area to ensure that the soil is not measurably impacted and that remedial actions can be implemented before damage to soil takes place. Actions levels would be based on soil type, crop type, irrigation water quality, amendments used, land use, beneficial use goals and landowner input. The quantitative measurements of average root zone EC and ESP would be the primary means to assess the potential impact of water on soils. With respect to salinity, as measured by the average root zone EC, the action level would be based on an appropriate salinity yield threshold for the selected crop species.

Because a soil characterized by a relatively high EC can maintain its physical integrity even when it has a high ESP (ESP>15) and the soils with a low EC could disperse even if the soil is characterized with a ESP of less than 5, the interaction between salinity and sodicity is an important relationship that requires both parameters to be assessed together when determining if a soil may be impacted by the applied water. Generally, if the soil EC is less than or equal to 3 dS/m, then the ESP should be less than or equal to 8 and if the EC is greater than 3 dS/m, then the ESP should be less than or equal to 15.

Corrective measures would be taken if the average root zone soil chemistry results for any monitoring period indicate values outside the guidelines. Initial response measures may include infiltration measurements for comparison to baseline values. Significant decreases in soil infiltration would indicate that impacts to soil structure are occurring. Corrective measures at that point include, but are not limited to, halting or reducing the application of produced water, applying additional amendments, application of gypsum at the end of the irrigation season to reduce the ESP during winter and spring snowmelt and rainfall events and/or using a less sodic water supply.

Comparison of Acres of Vegetation Disturbed

	Alt A	Alt B	Alt C
Long Term			
Roads			
All Weather	10	13	13
2-Track	20	32	32
	30	45	45
Compressor Sites			
Field Compressors	6	8	8
Sales Compressor	4	4	4
	10	12	12
Water Management			
Impoundments	80	80	80
Discharge Points	1	1	1
	81	81	81
Total Long Term	121	138	138
Short Term			
Well Sites			
State Well Sites	4	4	4
Private Well Sites	18	18	18
Federal Well Sites	0	18	18
	22	40	40
Flowlines			
Gas/Water Flowlines (from wells)	29.5	80	80
Produced Water Flowlines (to river)	6	6	6
	36	86	86
Powerlines			
Arial	6.5	9.5	9.5
Buried	14.5	24.5	24.5
	21	34	34
Total Short Term	79	160	160
TOTAL	200	298	298